

Search for High-Mass Resonances in the Dilepton Final State with the CMS Detector.

Vladlen Timciuc for the CMS Collaboration
California Institute of Technology,
Pasadena CA 91125 USA

A search for narrow resonances at high mass in the dimuon and dielectron channels has been performed by the CMS experiment at the CERN LHC, using pp collision data recorded at $\sqrt{s} = 7$ TeV. The event samples correspond to an integrated luminosity of 1.1 fb^{-1} . Heavy dilepton resonances are predicted in theoretical models with extra gauge bosons (Z') or as Kaluza–Klein graviton excitations (G_{KK}) in the Randall–Sundrum model. Upper limits on the inclusive cross section of $Z'(G_{KK}) \rightarrow \ell^+\ell^-$ relative to $Z \rightarrow \ell^+\ell^-$ are presented. These limits exclude at 95% confidence level a Z' with standard-model-like couplings below 1940 GeV, the superstring-inspired Z'_ψ below 1620 GeV, and, for values of the coupling parameter k/\bar{M}_{Pl} of 0.05 (0.1), Kaluza–Klein gravitons below 1450 (1780) GeV.

1. INTRODUCTION

Many models of new physics predict the existence of narrow resonances, possibly at the TeV mass scale, that decay to a pair of charged leptons. We present results of a search for resonant signal that can be detected by the Compact Muon Solenoid (CMS) [1] detector at the Large Hadron Collider (LHC) [2] at CERN. The results were obtained from an analysis of data recorded in 2011, corresponding to an integrated luminosity of 1.1 fb^{-1} , obtained from pp collisions at a centre-of-mass energy of 7 TeV. The complete analysis is reported in [3].

We perform a generic shape-based search for a narrow resonance, making no assumption on the absolute background rate. The Sequential Standard Model Z'_{SSM} with standard-model-like couplings, the Z'_ψ predicted by grand unified theories [4], and Kaluza–Klein graviton excitations arising in the Randall–Sundrum (RS) model of extra dimensions [5] were used as benchmarks.

2. LEPTON SELECTION

The reconstruction, identification, and calibration of muons and electrons follow standard CMS methods. Combinations of test beam, cosmic-ray muons, and data from proton collisions have been used to calibrate the relevant detector systems for both muons and electrons.

For both the dimuon and dielectron final states, two isolated same-flavour leptons that pass the lepton identification criteria are required. The two charges are required to have opposite sign in the case of dimuons (for which a charge misassignment implies a large momentum measurement error), but not in the case of dielectrons (for which charge assignment is decoupled from the electromagnetic calorimeter (ECAL)

energy measurement). An opposite-charge requirement for dielectrons would lead to a loss of signal efficiency of a few percent. The electron sample requires at least one electron candidate in the ECAL barrel (pseudorapidity range $|\eta| < 1.479$), because events with both electrons in the endcaps ($1.479 < |\eta| < 2.5$) have a lower signal-to-background ratio as a result of a higher rate of jets faking electrons. For the muon sample muons reconstructed in full muon system coverage region ($|\eta| < 2.4$) are used in the analysis.

The performance of the detector systems is established using measurements of standard model (SM) W and Z processes with leptonic final states and using traversing cosmic-ray muons. The dimuon mass resolution is estimated to be 4% at 500 GeV and 7% at 1 TeV. The dielectron mass resolution is more or less flat above 500 GeV. At 1 TeV the current mass resolution when both electrons are in the barrel acceptance is 1.3%, and when one electron is in the barrel and the other within the endcap acceptance the resolution is 2.4%.

3. BACKGROUNDS

The most prominent SM process that contributes to the dimuon and dielectron invariant mass spectra is Drell–Yan production (Z/γ^*); there are also contributions from $t\bar{t}$, tW , diboson, and $Z \rightarrow \tau\tau$ processes. In addition, jets may be misidentified as leptons and contribute to the dilepton invariant mass spectrum through multi-jet and vector boson + jet final states. The possible contamination from diphotons faking dielectrons has been found to be negligible.

To estimate contribution from Drell–Yan production the shape of the dilepton invariant mass spectrum is obtained from Monte Carlo (MC) simulation based on the PYTHIA [6] event generator. The simulated invariant mass spectrum is normalized to the data using the number of events in the mass interval

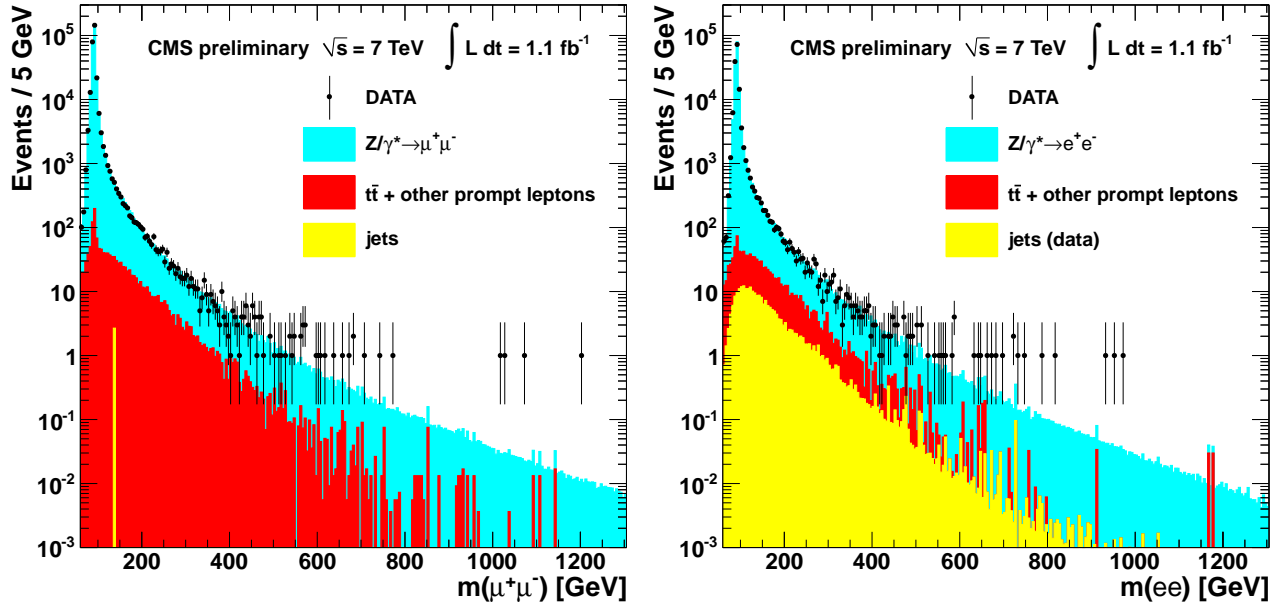


Figure 1: Invariant mass spectrum of $\mu^+\mu^-$ (left) and ee (right) events. The points with error bars represent the data. The uncertainties on the data points (statistical only) represent 68% confidence intervals for the Poisson means. The filled histograms represent the expectations from SM processes: Z/γ^* , $t\bar{t}$, other sources of prompt leptons (tW , diboson production, $Z \rightarrow \tau\tau$), and the multi-jet backgrounds.

of 60–120 GeV.

The dominant non-Drell–Yan electroweak contribution to high $m_{\ell\ell}$ masses is $t\bar{t}$; in addition there are contributions from tW and diboson production. Below the Z peak, $Z \rightarrow \tau\tau$ decays also contribute. Here we refer to leptons coming from the decay of a W or a Z as prompt leptons. All these processes are flavour symmetric, producing twice as many $e\mu$ pairs as ee or $\mu\mu$ pairs. The invariant mass spectrum from $e^\pm\mu^\mp$ events is expected to have the same shape as that of same flavour $\ell^+\ell^-$ events but without significant contamination from Drell–Yan production.

A good agreement was established between the observed and predicted $e^\pm\mu^\mp$ distributions, which provides a validation of the estimated contributions from the high-mass prompt lepton backgrounds obtained using MC simulation.

A further source of background arises when objects are falsely identified as leptons. The misidentification of jets as leptons, the principle source of such backgrounds, is more likely to occur for electrons than for muons.

Backgrounds arising from jets that are misidentified as electrons include $W \rightarrow e\nu + \text{jet}$ events with one jet misidentified as an electron, and also multi-jet events with two jets misidentified as electrons. Contribution from this background to the dielectron spectrum is estimated from the data based on the rate at which a jet can be misidentified as an electron.

Contribution from misidentified muons to the dimuon spectrum is estimated from MC, validated us-

ing similar method as for electrons, and in addition validated by analyzing same-charge muon pairs mass spectrum.

The $\mu^+\mu^-$ data sample is susceptible to contamination from traversing cosmic-ray muons, which may be misreconstructed as a pair of oppositely charged, high-momentum muons. Cosmic-ray events can be removed from the data sample due to their distinct topology (collinearity of two tracks associated with the same muon), and their uniform distribution of impact parameters with respect to the collision vertex.

4. DILEPTON INVARIANT MASS SPECTRA AND RESULTS

The measured dimuon and dielectron invariant mass spectra are displayed in Figs. 1(left) and (right) respectively. The expectations from the various background sources, Z/γ^* , $t\bar{t}$, other sources of prompt leptons (tW , diboson production, $Z \rightarrow \tau\tau$) and multi-jet events are overlaid. The prediction for Drell–Yan production of Z/γ^* is normalized to the observed $Z \rightarrow \ell\ell$ signal. All other MC predictions are normalized to the expected cross sections.

Good agreement is observed between data and the expectation from SM processes over the mass region above the Z peak, and limits are set on the possible contributions from a narrow heavy resonance. The parameter of interest is the ratio of the products of

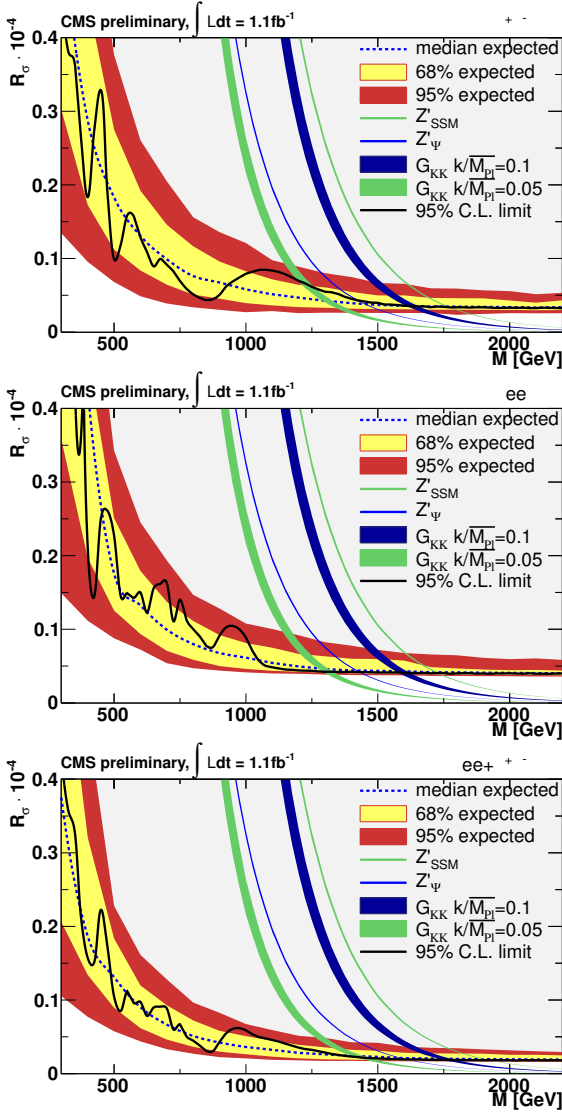


Figure 2: Upper limits as a function of resonance mass M , on the production ratio R_σ of cross section times branching fraction into lepton pairs for Z'_{SSM} and G_{KK} production and Z'_ψ boson production. The limits are shown from (top) the $\mu^+\mu^-$ final state, (middle) the ee final state and (bottom) the combined dilepton result. Shaded yellow and red bands correspond to the 68% and 95% quantiles for the expected limits. The predicted cross section ratios are shown as bands, with widths indicating the theoretical uncertainties.

cross sections and branching fractions:

$$R_\sigma = \frac{\sigma(\text{pp} \rightarrow Z' + X \rightarrow \ell\ell + X)}{\sigma(\text{pp} \rightarrow Z + X \rightarrow \ell\ell + X)}. \quad (1)$$

By focusing on the ratio R_σ , we eliminate the uncertainty in the integrated luminosity, reduce the dependence on experimental acceptance, trigger, and offline efficiencies, and generally obtain a more robust result.

Confidence intervals are computed using both frequentist and Bayesian approaches. The upper limits on R_σ (Eq. 1) from the various approaches are similar, and we report the Bayesian result for definiteness. From the dimuon and dielectron data, we obtain the upper limits on the cross section ratio R_σ at 95% confidence level (C.L.) shown in Figs. 2(upper) and (middle), respectively, and the combined limit (bottom).

5. CONCLUSION

The CMS Collaboration has searched for narrow resonances in the invariant mass spectrum of dimuon and dielectron final states in event samples corresponding to an integrated luminosity of 1.1 fb^{-1} , taken at a centre-of-mass energy of 7 TeV. The spectra are consistent with expectations from the standard model and upper limits have been set on the cross section times branching fraction for Z' into lepton pairs relative to standard model Z boson production. Mass limits have been set on neutral gauge bosons Z' and RS Kaluza–Klein gravitons G_{KK} . A Z' with standard-model-like couplings can be excluded below 1940 GeV, the superstring-inspired Z'_ψ below 1620 GeV, and RS Kaluza–Klein gravitons below 1450 (1780) GeV for couplings of 0.05 (0.10), all at 95% C.L.

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